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The Navy is developing sonobuoy-sized, air-deployed, satellite-tracked, drifting data buoys. The buoys send 10-min averages of air pressure, air temperature, and water temperatures. Water temperatures are at 0, 5, 10, 20, 30, 50, and 100 m below the surface. The buoys have two purposes. First, they collect and relay data from remote or violent-weather areas. Second, they help interpret near-surface current patterns by their drift tracks.

Last year, the Navy tested 60 of these buoys. Tests were in the Gulf of Mexico, Mediterranean, Northwest Pacific, and Northeast Atlantic. Results showed buoy sensors are reasonable accurate. However, subsurface sensors do not survive for the three-month design lifetime. Although surface sensors rarely failed within three months, one-third of subsurface sensors typically failed within one month.

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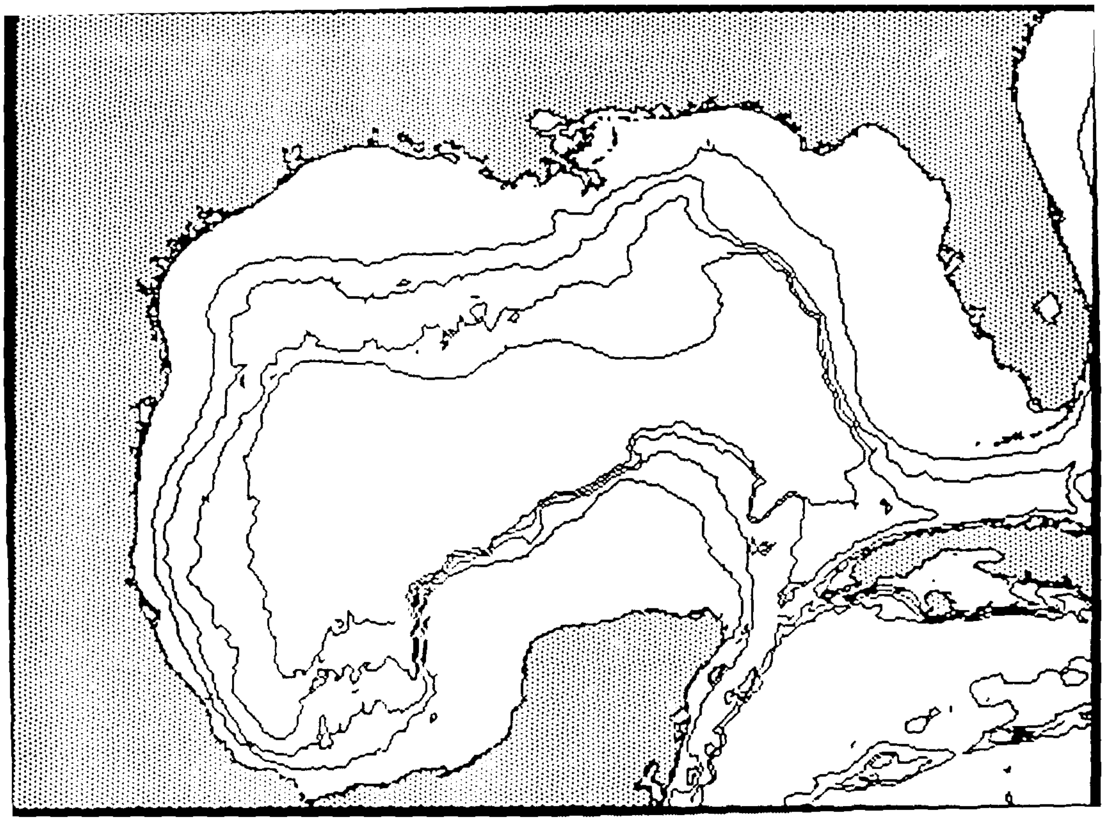

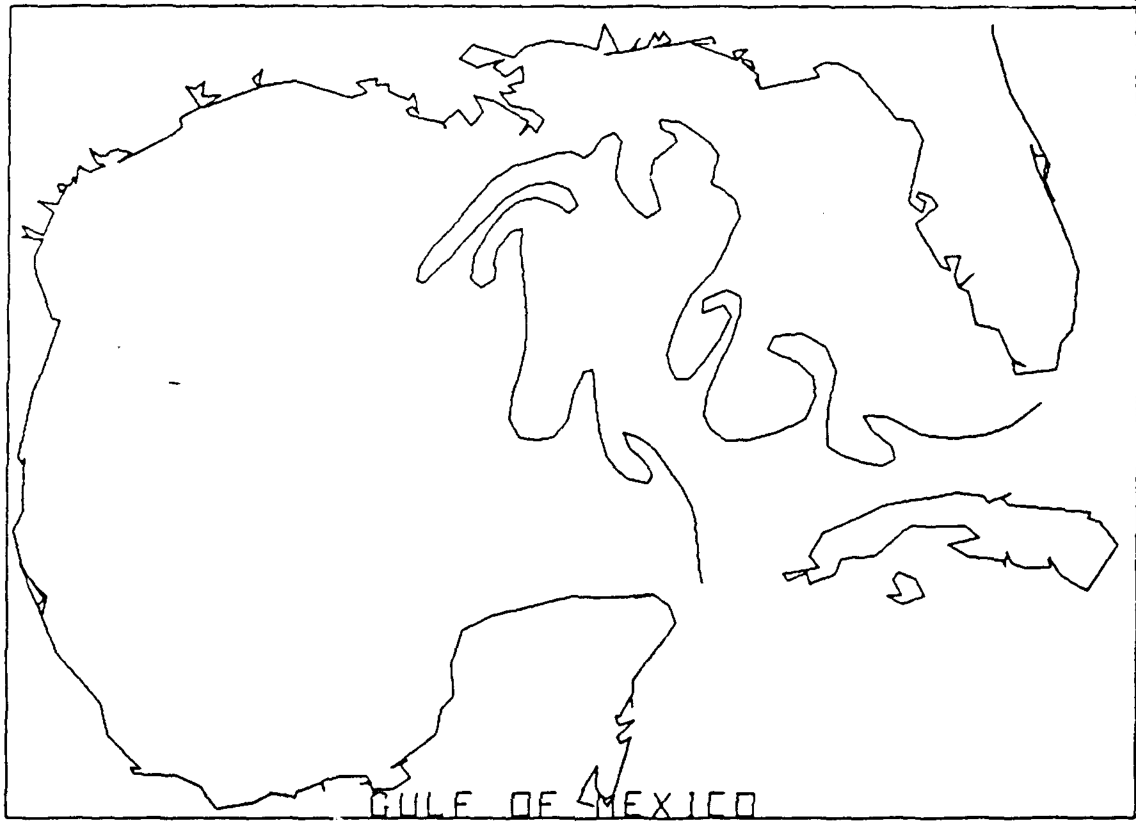

Figure 13.1. Loop Current on April 27, 1989. (GULFPLOT digital chart by Evans-Hamilton, Inc. from National Oceanic and Atmospheric Administration analysis.)

Mr. Jeffrey Cox is Vice-President and Manager of the Seattle office of Evans-Hamilton, Inc. He received his B.S. in oceanography from the University of Washington in 1977, and since then has been conducting studies of the transport and impact of marine pollutants in coastal and estuarine environments. He has participated in studies of the Gulf Stream, its fluctuations, and resulting Atlantic cold-core eddies during POLYMODE and during the Frontal Eddy Dynamics Study off North Carolina for the Minerals Management Service. Over the past four years he has been involved in the data collection and analysis of several Loop Current derived features and, in particular, Nelson Eddy.

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U.S. NAVY TESTS OF SONOBUOY-SIZE OCEANOGRAPHIC BUOYS

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ABSTRACT

The Navy is developing sonobuoy-sized, air-deployed, satellite-tracked, drifting data buoys. The buoys send 10-min averages of air pressure, air

temperature, and water temperatures. Water temperatures are at 0, 5, 10, 20, 30, 50, and 100 m below the surface.

The buoys have two purposes. First, they collect and relay data from remote or violent-weather areas. Second, they help interpret near-surface current patterns by their drift tracks.

Last year, the Navy tested 60 of these buoys. Tests were in the Gulf of Mexico, Mediterranean, Northwest Pacific, and Northeast Atlantic. Results showed buoy sensors are reasonably accurate. However, subsurface sensors do not survive for the three-month design lifetime. Although surface sensors rarely failed within three months, one-third of subsurface sensors typically failed within one month.

INTRODUCTION

Buoy Uses--Remote Data and Circulation

The U.S. Navy uses drifting buoys for gathering data in inaccessible areas and for interpreting surface currents.

As remote data stations, buoys have to be both expendable and rugged. They should also deploy easily from either ships or aircraft. The Navy uses them in regions where heavy weather has driven out traffic or in regions where there is no traffic. In either case, buoys are never recovered or repaired. Both the U.S. Coast Guard (Thayer *et al.* 1988) and the Navy (Pickett 1989b) are testing such buoys.

Another buoy application is in circulation studies. The buoys can help predict motions of sonobuoy arrays (Pickett and Burns 1987; Burns and Pickett 1988) and can provide data to prime models. They are also valuable in interpreting satellite images (Pickett *et al.* 1984).

As remote data stations, the buoys work well. However, in circulation studies, they have limitations. Satellite-derived positions are several hours apart and only accurate to about 0.3 km (Pickett *et al.* 1983). In addition, wind introduces drift errors (Pickett 1989a). Hence these buoys can accurately track only large-scale, strong currents in light to moderate winds.

Weather Buoy--Worked Well

Last year we tested a weather buoy designed to meet the above needs (Pickett 1989c). These buoys relayed 10-min averages of air pressure, air temperature, and sea-surface temperature via satellite. They were expendable, with a design lifetime of three months. The buoy package is a standard sonobuoy container (36 inches long, 4.9 inches diameter, 25 lbs) (Figure 13.2). They cost $2,750 each and can be launched from either ships or aircraft.

From aircraft, the buoy launch envelope was 300 to 30,000 ft. altitude, and 0 to 300 kts air speed. A self-deploying parachute slowed descent, and a seawater-switch activated the buoy. The switch caused the sonobuoy container to fall away, a flotation collar to inflate, and an antenna to pop up. The container, attached to the bottom of the buoy with a 100-m cable, acted as a drogue.

Once the buoys were in the water, the data were satellite-relayed about every three hours at 30°N and more frequently at higher latitudes. Service ARGOS, the data-processing company, gathered the satellite data from several receiving stations around the world. Next, the company converted the data to standard units and formats. Finally, they loaded the converted data on international weather networks. Weather facilities around the world received the buoy's data within a few hours. Figure 13.3 shows the buoy's data format sent over the networks.

Many Navy facilities, however, no longer rely on the above data-relay system. They can receive buoy data directly and more quickly with their own satellite-receiving stations.

Our tests of this buoy uncovered two major problems. First, lifetimes were less than three months. Second, buoys failed at aircraft launch speeds above 250 kts.

We traced lifetime problems to the flotation-collar gas. Carbon dioxide either reacted with, or diffused through, the collar fabric. When we changed the gas to nitrogen, lifetimes increased to three months.

Higher-speed launches required some redesign and an external wind-flap support. With these changes, the buoy then survived launches up to 300 kts.

After we fixed the above two problems, the buoys passed all our tests. The Navy then bought several hundred and used them operationally around the world.

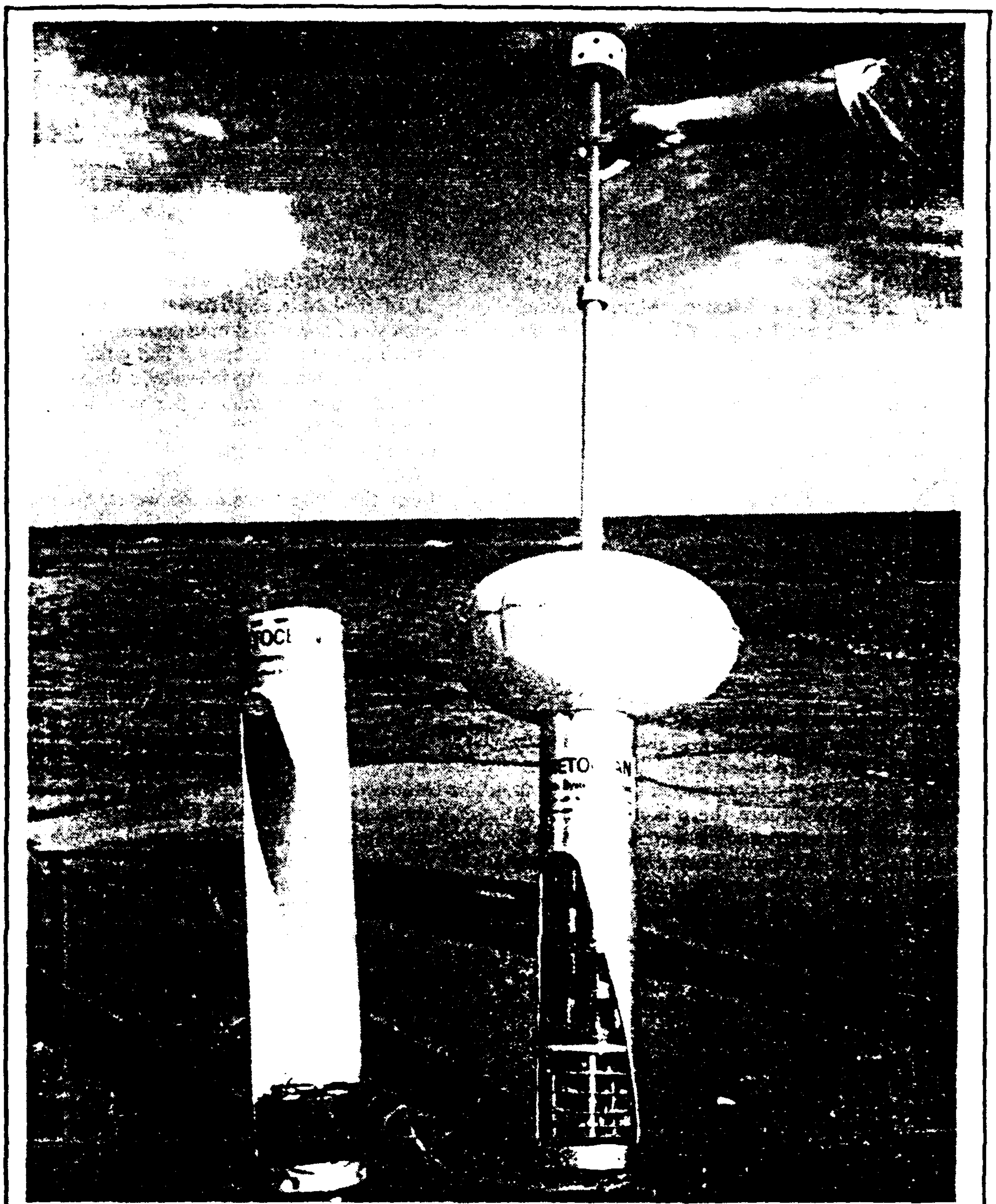

Figure 13.2. A fully deployed buoy (cut open to show insides). (The surface unit is on the right, and the launch container on the left. The surface unit houses the air-pressure port and air temperature sensor in a white knob at the top [above the antenna]. The sea-surface temperature sensor is at the bottom of the surface unit. The subsurface temperature cable is still on the spool at the bottom of the launch container. All electronics [data sampling, averaging, transmitter] are on five circular boards at the bottom of the surface unit. Above these boards is the power stack of C-cell batteries.)

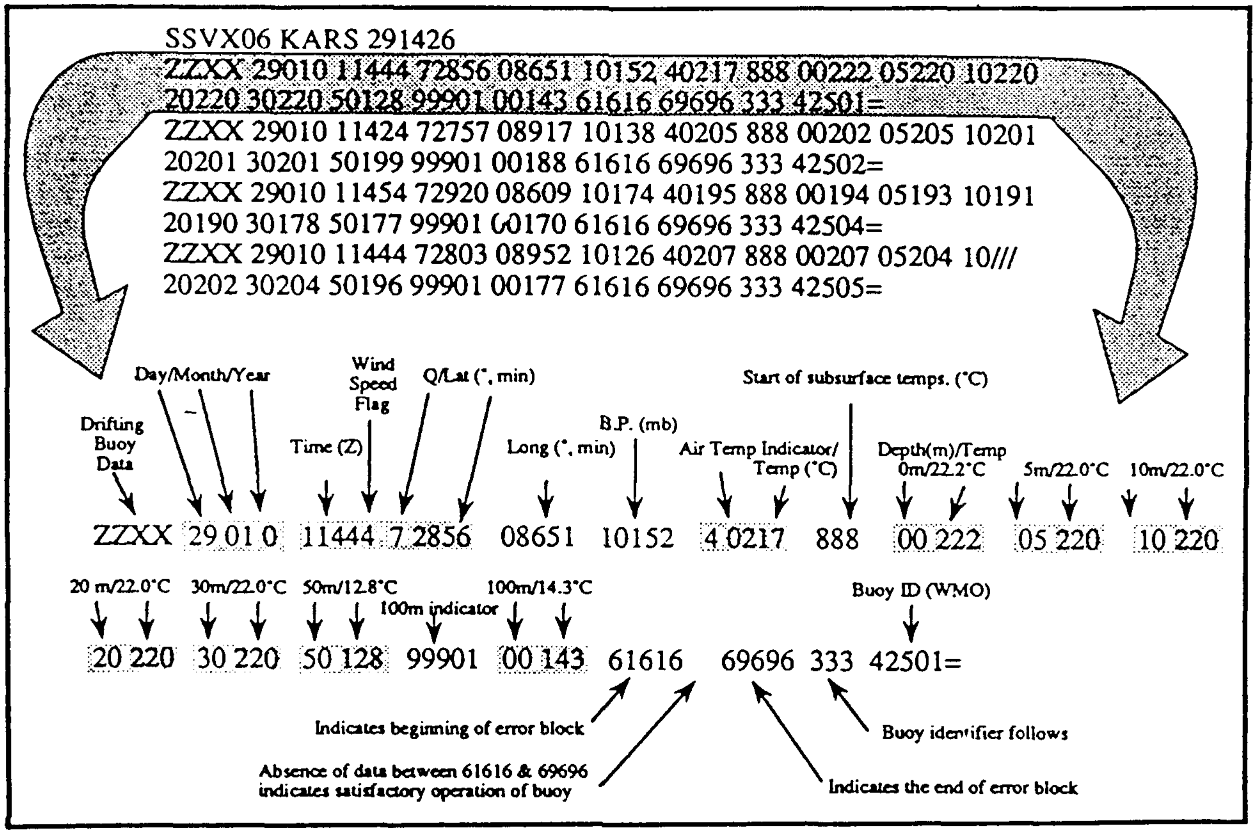

Figure 13.3. A sample message from a buoy. (The first line of each message begins with the SSVX06 KARS identifier followed by the day and time [GMT]. Typically one message contains data from all buoys in an area. The second line starts with ZZXX, which separates data from each buoy. The next two words are the date and time of the data. The rest of the words are: latitude, longitude, air pressure, air temperature and, finally, the subsurface temperatures.)

Improved Buoy--Subsurface Temperatures

This year, we began testing an extended version of the same buoy (Figure 13.2). The new buoys cost $4,000 each. Packaging and launching are unchanged. The major difference is that the drogue line now contains temperature sensors. Hence in addition to the same surface sensors, the new buoys also measure 10-minute averages of seven levels of water temperature. The seven levels are 0, 5, 10, 20, 30, 50, and 100 m below the surface.

The addition of the temperature cable also required three minor design changes. First, the external container falls away, rather than becoming a drogue. This is done to avoid possible sensor-cable damage. Second, the cable has an end-weight to keep it more vertical. Third, the bottom of the cable has a pressure sensor to measure cable tilt.

FIELD TESTS

Lake Michigan--Accuracy Tests

The first at-sea test of the subsurface-sensor buoys was in Lake Michigan. The lake was chosen for three reasons. First, there was a moored weather station at its center. Second, the lake had a strong thermocline within the 100-m length of the temperature tail. Third, the lake offered a better chance of recovering the buoys than the open ocean.

To check sensor accuracy, we deployed two buoys by ship on 7 September 1989 beside the weather station. We recovered the buoys on 26 September. During this drift period, one buoy remained within 35 km of the station, but the other drifted 70 km away.

Details of this accuracy test are in McCormick *et al.* 1990. In general, the results showed all buoy surface sensors compared well with the weather station's data. The buoys' subsurface temperatures also compared well to a conductivity-temperature-depth instrument. Figure 13.4 is a sample of these comparisons.

Buoy surface water temperatures are warmer because the buoy only measures 0.5 m below the surface. By contrast, the weather station measures 1 m below the surface (note near-surface, temperature slope in last panel). Similarly, buoy air temperatures are higher because they are closer to the water surface (1 m instead of weather station's 5 m). Allowing for these differences, buoys sensors seem reasonably accurate.

Although buoy-sensor accuracies were close to specifications, subsurface-sensor lifetime was not. All subsurface temperature sensors on both buoys failed within two weeks. As a result, we stopped the test and recovered the buoys for analysis.

Studying the condition of the recovered buoys, we made three changes to the subsurface cable. First, we molded the thermistors directly into the cable, instead of a less-protected breakout system. Second, we added a stronger, load-bearing bushing between the buoy and the top of the cable. Third, we added a tripod suspension above the bottom weight to strengthen the attachment and reduce spinning.

Gulf of Mexico--Air Launch

After the above redesign, we shifted testing to the Gulf of Mexico. In this series, we also added the rigor of aircraft deployment.

For the first test, two buoys were air dropped in November 1989 at the same location in the northern Gulf of Mexico. We then compared the first 10 days of surface data from the buoys before they drifted apart. The object was to test if high speed launch and water impact altered sensor accuracy. We calculated differences between simultaneous buoy measurements of air pressure, sea surface temperature, and air temperature.

The above test showed the mean and standard deviation of the air pressure differences were 0.3 mb and 0.4 mb. The mean and standard deviation of sea surface temperature differences were 0.1° and 0.1°C. For air temperature, the mean difference was 0.0°C and the standard deviation was 0.1°C.

Although the above data show all surface sensors survived air launch with no loss of accuracy, subsurface sensors on both buoys soon developed problems. Bottom pressure sensors failed within in a few days. In addition, one subsurface temperature sensor on each buoy failed within a week.

To develop better statistics on subsurface failures, we air-launched 17 more buoys in the Gulf. Minor changes followed each drop as we tried to increase subsurface-sensor lifetimes. None of these changes was very successful. By the time we finished these drops, bottom-pressure sensors still failed in a few days and subsurface-temperature sensors in a few weeks. Eventually, we managed to recover three of these failed buoys for analysis.

While we analyzed these recovered buoys, we also ran pressure tests on a subsurface-temperature cable. We put the tail of an operating buoy in a seawater pressure tank at a pressure equivalent of 200-m depth (twice the operating depth). After two weeks, all subsurface sensors still operated. We concluded seawater pressure alone was not causing early failures.

After studying the three buoys recovered from the Gulf of Mexico, we tried a new, less-permeable potting compound for the cable sensors. We also reduced the size of the bottom weight to reduce cable stress.

Engineers at the Naval Avionics Center had already suggested reducing the bottom weight. A stress-simulation model run at the Naval Oceanographic Office confirmed their suggestion. The model showed the bottom weight was heavy enough to stress the conductors inside the cable in steep seas. In addition, the bottom pressure sensor never recorded significant cable lift on buoys at sea. As a result of the above suggestions, models, and observations, we reduced the end weight from 2 to 1.5 lbs.

Operational Tests--Buoys Pass

While completing the above redesigns, we tested some more buoys in military operations. The object was to find out if there were any special problems associated with military applications anywhere in the world.

During late 1989 and early 1990, Navy aircraft launched three buoys off Iceland and four in the Mediterranean. The Air Force also launched two in the northeast Pacific.

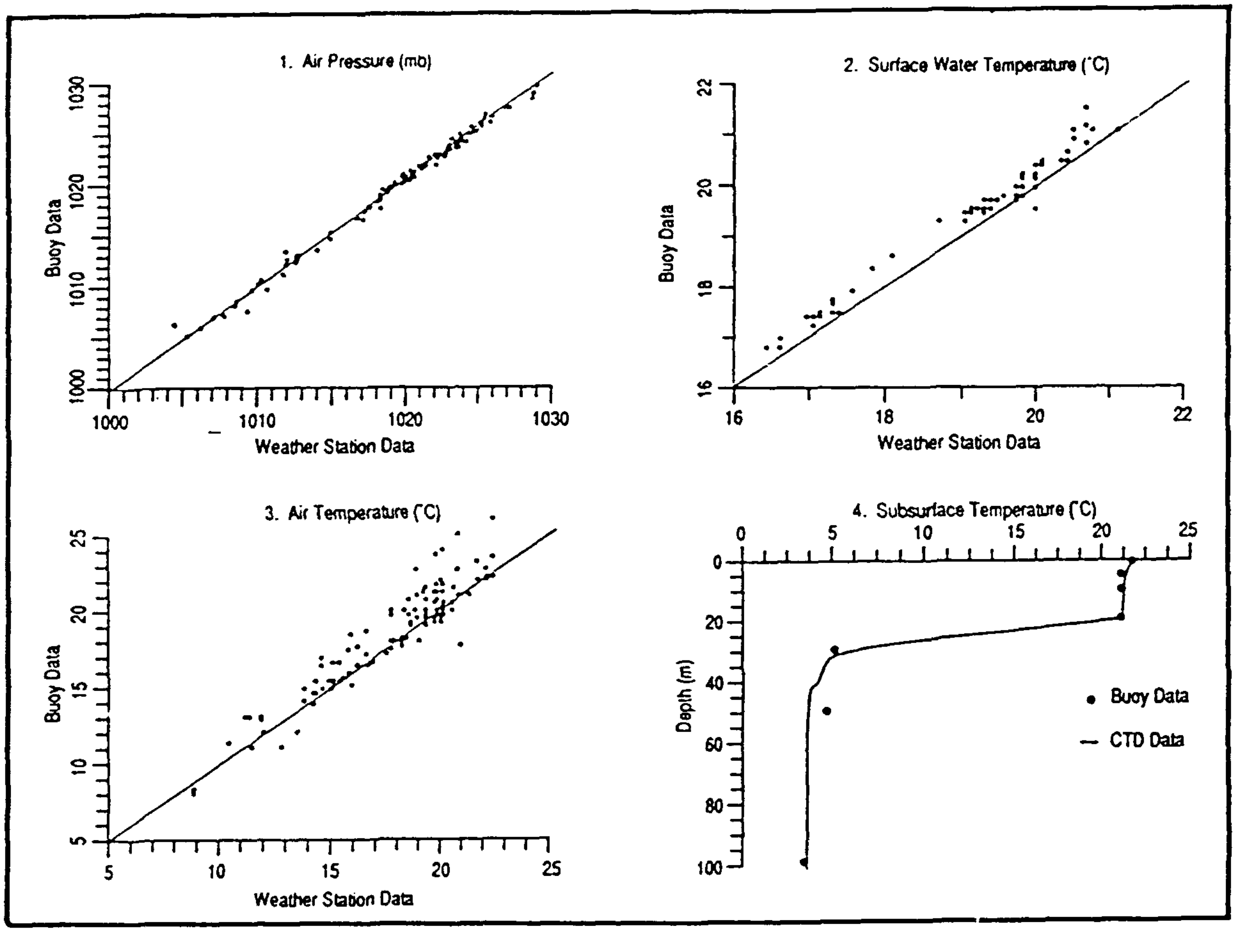

Figure 13.4. Air pressure and water and air temperature comparisons in September 1989 in Lake Michigan (from McCormick *et al.* 1990). (A weather station at the buoy launch site provided the surface reference data. A conductivity-temperature-salinity instrument provided the subsurface reference data.)

All these tests were successful. All buoys survived deployment, provided necessary data, and lasted throughout the operations (a week or two). We also discovered by accident that our subsurface sensors seem to survive longer in cooler waters. The reason for this is unclear.

Figure 13.5 shows the subsurface-sensor lifetimes on the four operationally buoys air launched in the Mediterranean Sea in February 1990. Although the mean lifetimes did not reach the 90-day design goal, they were greater than any group of buoys we tested so far.

Gulf of Mexico Again--Cables Fail

In January 1990, we dropped six buoys with new potting and lighter end weights in the Gulf. Figure 13.6 shows the survival rate for these buoys. In general, lifetimes are shorter in the Gulf of Mexico than the Mediterranean. Further, the 100-m sensors failed very quickly (10 to 15 days).

Still more changes followed the above tests. The latest redesign included all previous improvements, plus three new ones. First, we moved the bottom pressure sensor 0.5 m below the bottom temperature sensor. This was done so we could make 100-m temperature sensors exactly like the upper ones. We hoped they would then match the reliability of the upper sensors. The second change involved electronic improvements to reduce potential voltage spikes that could damage circuits. Finally, we reduced the end weight once again from 1.5 to 1.0 lbs to reduce cable stress further.

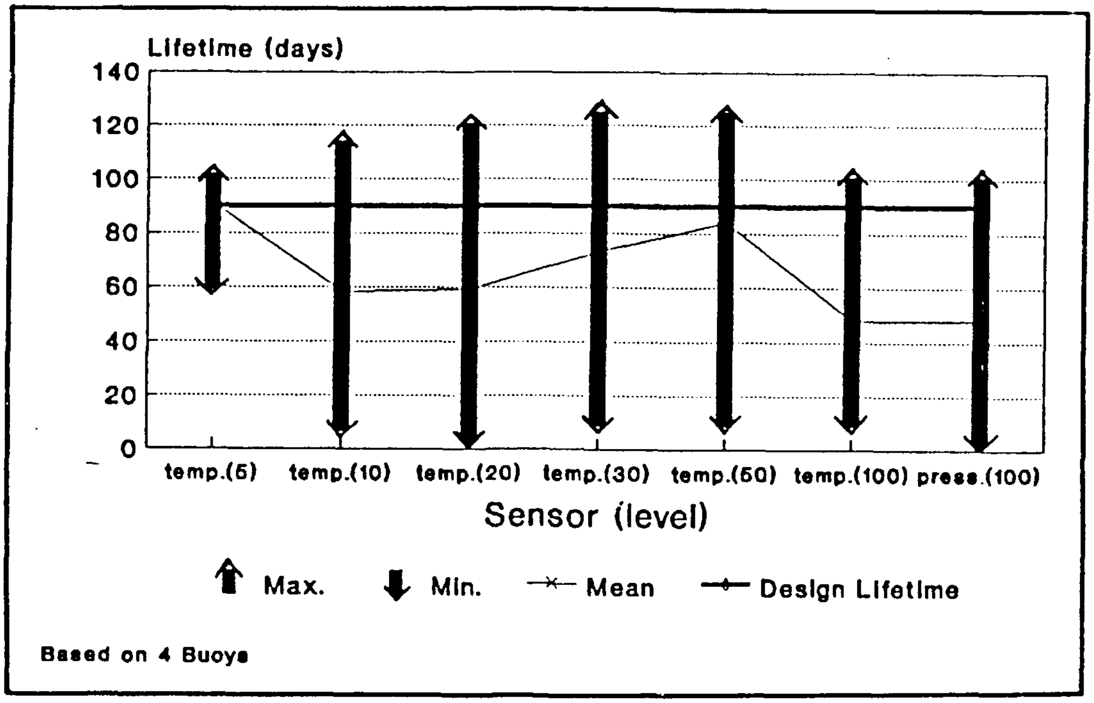

Figure 13.5. Survival rates for buoy subsurface sensors - February 1990. (The figure covers four buoys launched in the Mediterranean Sea during February 1990. The vertical bars extend from the minimum to the maximum sensor lifetime at each depth. The flat line near the top is the design goal of 90 days. The other line connects the mean sensor lifetime for each level. There is a large range in sensor lifetimes among buoys. However, these subsurface sensors in the cool Mediterranean lasted longer than any others.)

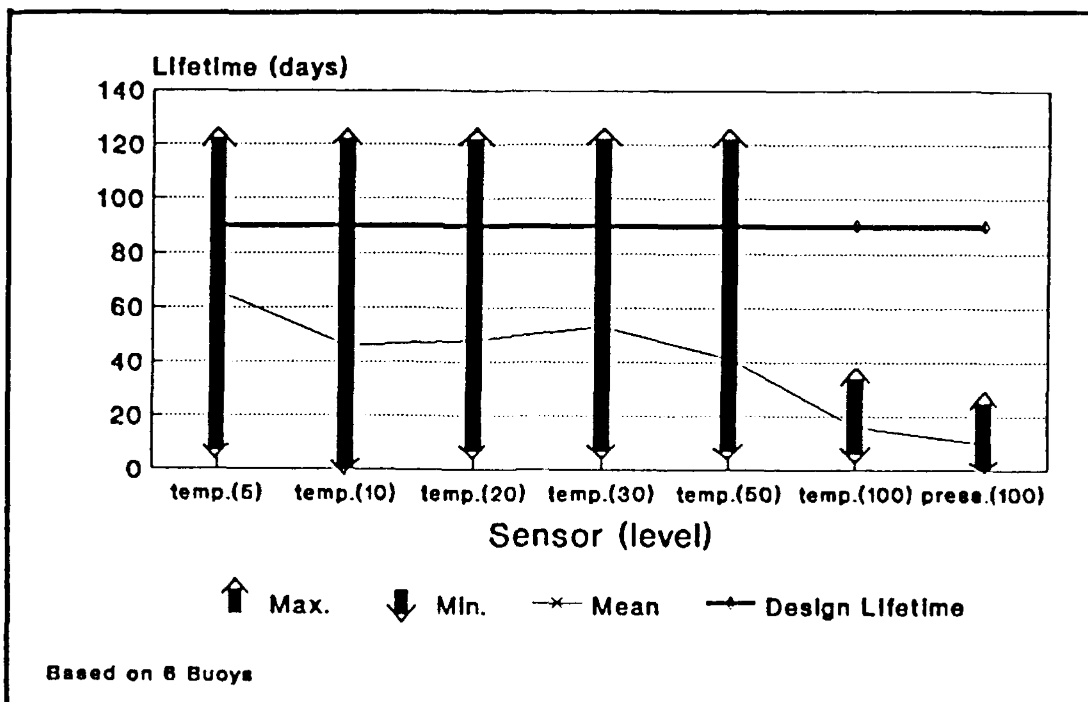

Figure 13.6. Same as Figure 13.5, except data are for six buoys launched in winter 1989-1990 in Gulf of Mexico. (Lifetimes were less than in the Mediterranean Sea.)

We dropped 10 of these latest buoys in the Gulf in August 1990. One buoy did not deploy, but Figure 13.7 shows the survival of the other nine. In spite of all of the above improvements, the subsurface-sensor lifetimes actually declined, averaging only about 20 days. Our only explanation is that increasing water temperatures increase failures faster than we are improving the buoys.

DATA FLOW

Communications--Getting Bugs Out

Along with the above survival problems, we also uncovered communication problems during the above tests. First, buoy messages had parts cut off. Service ARGOS had to fix their automatic data-processing programs. Second, Navy facilities were not receiving some messages. This was a routing problem at the gateway to the international weather networks. Third, the Fleet Numerical Oceanography Center did not have programs in place to receive buoy-subsurface data. Fourth, after any buoy sensor failed, there was no way to remove its bad data from the weather network.

Eventually we solved ıll the above communication problems. In addition, we installed an automatic editor (Teague *et al.* 1986) in the data stream at Service ARGOS. During data processing, the editor automatically checks for bad data. If any sensor fails the tests, the editor switches to a missing data code.

Data Display--Software Help

Navy facilities quickly ran into problems dealing with our large quantities of buoy data. Since every buoy sends about 70 observations per day (9 sensors, 8 data relays), the output from a group of buoys is large. Six of our Gulf buoys, for example, sent more subsurface temperatures over the networks than the rest of the world combined.

As a result, the facilities needed easy-to-use methods to extract (from the format shown in Figure 13.3) and display buoy data. In response, we wrote and

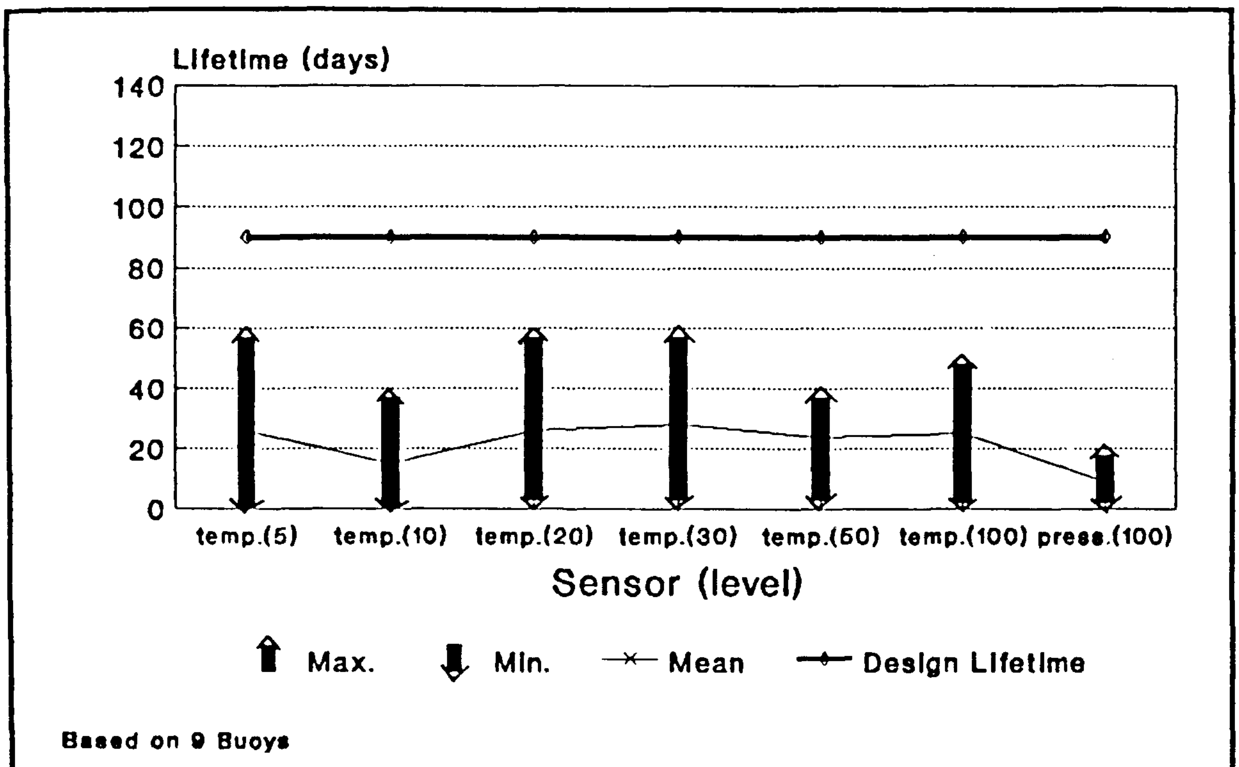

Figure 13.7. Survival rates for buoy subsurface sensors – summer 1990. (The figure covers nine buoys launched in the Gulf of Mexico during summer 1990. The vertical bars extend from the minimum to the maximum sensor lifetime at each depth. The flat line near the top is the design goal of 90 days. The other line connects the mean sensor lifetime for each level. Lifetimes were the shortest yet in this warm water.)

sent them a series of programs to capture and display buoy data.

SUMMARY

In Lake Michigan, buoy sensors compared well with the reference weather station. After aircraft launch into the Gulf of Mexico, buoy sensors also compared well with each other.

Although buoy sensors were accurate, subsurface sensors failed before their three-month design lifetime. One-third of all subsurface sensors failed within about 30 days. At present, these early failures are our major problem.

In addition, we have two minor problems. First, there are occasional bad barometers. In the recent lots of buoys we tested, about 20% of the barometers were not within specifications ($\pm$ 0.1 mb).

Second, after tail sensors fail, their output drifts. Typically they drift in and out of reasonable bounds. This drifting allows bad data to go through the editor and over the networks. Ideally, once a sensor fails, it should go to an out-of-range value and stay there.

We hope to fix the above three problems soon. A better understanding of tail failures, barometer tests, and internal software changes should lead to solutions for the above problems. In our next series of tests, for example, we will load buoys with diagnostic sensors to detect cable problems. Also, we will continue to try to recover buoys at sea to analyze failures.

Once we solve the above problems, we plan to extend the subsurface cable from 100 m down to 300 m. The result of these efforts should be a buoy with accurate sensors that lasts three months at sea. Such a buoy would satisfy both Navy requirements. It could provide data in remote or dangerous regions, as well as estimates of near-surface currents.

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Dr. Robert L. Pickett has worked in the Physical Oceanography Branch of Naval Oceanographic and Atmospheric Research Laboratories for the past eight years. His areas of research have recently focused on the development and testing of expendable drifting buoys capable of being deployed from standard sonobuoy tubes now available on Naval aircraft around the world. Dr. Pickett received his Ph.D. in oceanography from William and Mary.

Mr. A. C. MacAdam is a mechanical engineer with METOCEAN Data Systems, Ltd. in Dartmouth,

Nova Scotia, Canada. He has been involved with the design of drifting data buoys for the U.S. Navy for the past three years. He has been responsible for the design and implementation of the temperature-sensing cable of the drifters described herein.

QUIET EDDY, 1990

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During the summer of 1990, the Loop Current pushed northward south of the Mississippi Delta, where a diverse range of eddies and other circulations was formed. The major eddy formed at this time was nicknamed Quiet Eddy. Although the surge and eddy separation occurred during the summer months, when atmospheric moisture generally precludes tracking of these features by satellite imagery, the surge northward and eddy formation were well documented through hydrographic surveys and drifting buoys. Additionally, the fine structure of the Loop Current/Eddy fronts is revealed by cool water upwelled near the region of strongest currents.

Throughout the late spring and summer, the general circulation of the Gulf was defined by the drifting buoys deployed. During May and June, additional details of the circulation were revealed by Expendable Bathythermographs (XBTs) deployed during the National Marine Fisheries Service Ichthyoplankton Surveys, as well as other satellite-telemetered XBTs. During July, the routine satellite-telemetered XBTs and drifting buoy data were supplemented with an XBT and acoustic Doppler current profiler transect across the Loop Current.

After high currents entered the deepwater lease areas in August, detailed hydrographic and current sampling began. These surveys, combined with the buoy and satellite data, give a detailed picture of the separation of the eddy from the Loop Current.

Mr. Ken J. Schaudt is an oceanographer and meteorologist with Marathon Oil Company and Chairman of the Eddy Joint Industry Projects. His primary activities are support of Marathon's worldwide exploration and production operations. Mr. Schaudt holds a B.S. and an M.S. in atmospheric and oceanic science from the University of Michigan.

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Dr. George Z. Forristall is a Staff Research Engineer in the Oceanographic Engineering Department of Shell Development Company. He has a Ph.D. in mechanical engineering from Rice University. Most of his work has been on storm driven waves and currents, but recently he has become interested in mesoscale circulation features and their effect on offshore structures.

Dr. Cort Cooper is a physical oceanographer with Chevron Oil Company. He is active in eddy studies and circulation modeling.

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